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THE TEACHING OF SCIENCE

By

SHERWIN MAESER



ELEVENTH ANNUAL FACULTY RESEARCH LECTURE

The Teaching of Science

By

SHERWIN MAESER

Professor of Chemistry

THE FACULTY ASSOCIATION
UTAH STATE AGRICULTURAL COLLEGE
LOGAN UTAH—1952

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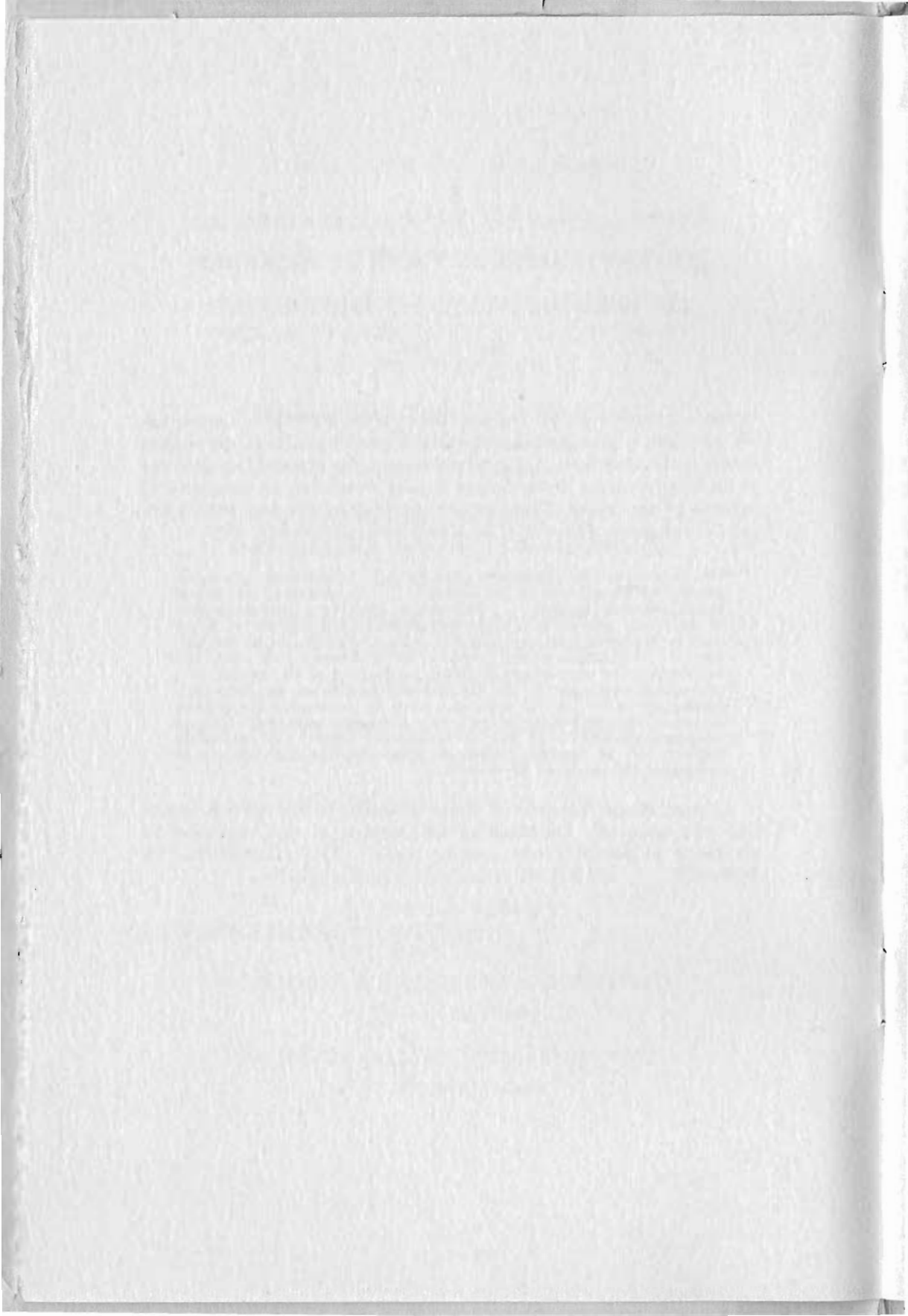
MAY 9, 1952

THIS LECTURE by Doctor Sherwin Maeser is the eleventh in a series, one of which is presented annually by a scholar chosen from the resident faculty at the Utah State Agricultural College. The occasion expresses one of the broad purposes of the College Faculty Association, an association of members of the faculty. These lectures appear under the Association's auspices as defined in article II of its Constitution, amended in 1951:

The purposes of the organization shall be . . . to encourage intellectual growth and development of its members . . . by sponsoring an Annual Faculty Research Lecture . . . The lecturer shall be a resident member of the faculty selected by a committee of seven members, one of whom shall be appointed from the faculty of each of the Schools of the College . . . In choosing the lecturers, the Committee shall take into consideration the achievements of faculty members in all the various areas of learning represented by the teaching and research of the Institution. Among the factors to be considered shall be outstanding achievement in one or more of the following: (1) publication of research through recognized channels in the field of the proposed lecture; (2) outstanding teaching over an extended period of years; (3) personal influence in developing the characters of students.

Doctor Maeser was selected by the committee to the eleventh lectureship thus sponsored. On behalf of the members of the Association we are happy to present Doctor Maeser's paper: THE TEACHING OF SCIENCE.

COMMITTEE ON FACULTY RESEARCH



FOREWORD



TO PRESENT a discussion on teaching as one of the Faculty Research Lectures may seem to be inconsistent. To do so can, however be justified by the fact that the selection committee knowingly chose for the speaker one whose work at the College has been almost wholly limited to teaching. If further justification is necessary it can be found in the obvious assumption that the future of research depends on the quality of the teaching practiced now.

After many years of teaching I believe that I can best meet the obligation that accompanies the honor of being selected for this lecture by calling attention to those things which seem to me to be of greatest importance in aiding in the preparation of our future leaders.

SHERWIN MAESER

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THE TEACHING OF SCIENCE

BY SHERWIN MAESER

Department of Chemistry
Utah State Agricultural College



LIKE TO teach! Whether with the expectant, half-frightened freshman, the senior, worried about his preparation now that he must get out and meet competition, or the graduate student interested in new discoveries, I like to work with all of them.

I have been teaching a long time now. As has always been the case when one generation is thinking of turning over its work to the next, I am glad to have the opportunity to talk about some of the things that I consider important in this job of teaching.

The most varied and the most acute problems of teaching in college are met with freshmen and sophomores. As a student advances in college he becomes less dependent on the teacher, though a good teacher is important at any stage of a student's education. It is during the earlier years of education that the influence of the teacher is greatest. My remarks will be directed chiefly to the problems of teaching the physical sciences to freshmen. Many of these problems are, however, common to the teaching of all subjects to all students.

Let us take a look at these freshmen. What are they like and why are they as they are? What can we expect of them? What should be our objectives in teaching them? How does science lend itself to the attaining of these objectives? Whatever these boys and girls are now, we must accept them as they are and do our best to help them to richer lives.

THE PRE-COLLEGE PREPARATION OF FRESHMEN

THANKS TO modern inventions and the modern school system the problems we meet are not as varied as they were a generation ago. The boy from the ranch in San Juan County has seen the same movies and heard the same radio programs as his new classmates from Ogden and Salt Lake City. He has likely made trips through the country, visiting cities, parks, and scenic wonders. With his athletic teams and brass bands he has met the boys and girls in schools at rather long distances from his home. For twelve of his eighteen years a large fraction of his waking hours has been spent in schools which do not differ greatly from most of the other schools of the state.

There was a time when a person as widely traveled as these boys and girls are and as sophisticated as they have become through movies, radio, and television and with twelve years of schooling, would have been considered a person of distinction in a community. Today he is just a freshman. He has learned to be a pleasant fellow. He meets strangers easily. You like him wholeheartedly. But surely in twelve years he should have learned to write an intelligent paragraph (on a subject of his own choosing—if you can get him to choose a subject). He cannot do it.

Freshmen's ignorance of geography is so appalling that one becomes embarrassed for them. Few freshmen students in my classes have known that Chile and Peru lie on the west coast of South America. If I wish to relate location of industries to the the Great Lakes and important waterways of the United States, they are lost. They are ignorant of the most important events of history. Some of the important advances of science began about the time of the French Revolution. The students do not even know that the French had a revolution.

Even the simplest of problems involving arithmetic frighten most freshmen. To determine the cost of seven-eighths of a ton of salt when the cost of two-fifths of a ton is given is an almost impossible task. Of the few students who will attempt the solution many will quote a lower cost for the seven-eighths ton than for the two-fifths ton without seeing that the answer is absurd. They want the instructor to give them the formula to use to solve every problem. If there are three numbers given in the problem they are most likely to put them into a ratio and proportion equation in which they use a large X for the equals sign. They will not, they cannot, concentrate on a question more than a minute or two at a time.

It does not occur to the freshman to use a dictionary when he meets an unfamiliar word in his reading. In fact, a dictionary only confuses him. He cannot understand the definition. His spelling is atrocious and often his penmanship is hardly legible.

My criticism of freshmen is severe. I am sure, however, that most of you who have worked with them will agree that it is justified. If you should take my criticisms, however, as evidence that I do not like them or have a low opinion of their capabilities, you would be mistaken. I believe that a serious mistake is made in many of our freshman classes by underestimating their abilities. Their sorry plight is a result of their past experiences and can be rectified, thanks to their inherent aptitudes, by vigorous remedies. It may be that the students who have elected my classes are not an average sample. Perhaps they have a little better I. Q. since they are mostly students who have chosen to major in the sciences. But I find that they soon learn to do hard work and like it.

WHY ARE HIGH SCHOOL GRADUATES POORLY PREPARED

IF STUDENTS entering our colleges have great inherent ability and yet are so incapable of solving simple problems, if they are unacquainted with history, geography, and great books, and cannot express themselves in understandable language, there can be only one explanation. A large part of the twelve years they have previously spent in school has been wasted. This condition is not confined to schools in Utah. A few years ago at an eastern university I found the same lack of proficiency in English and mathematics among freshmen. I had little opportunity to question them about history, geography, or literature, but from many of their questions and from their conversations I got the impression that they were not better prepared than our own. Many teachers in our colleges are beginning to speak about these things. Professor David Daiches (1951), who has been teaching at universities in the United States for ten years and is now returning to England, has this to say:

The best American student is as zealous for culture as anyone could possibly be, but he arrives at college with much less mathematics and science than his British opposite number, with virtually no history and probably no foreign language (not properly learned, anyway) with little skill in the use of his own language and with the feeling that it is reactionary to study the past. Freshman and sophomore years in college are devoted to trying to remedy this.

And later in the same article:

The waste of the younger years—the greatest of all for learning when curiosity is active and good habits of reading and writing can be cultivated—remains the real fault of modern American education.

At a recent meeting of the Utah Council on Higher Education, many of the speakers expressed the same opinion.

What changes in our high school curriculum are causing this ignorance and inability to think? Must we accept this condition as inevitable? Has education for discipline of the mind given way to something of more value?

THE TOOLS OF LEARNING ARE NEGLECTED

THERE WAS a time when teachers and school administrators thought that the first job to be done in a school was to supply the student with the most useful tools (the 3 R's) for aid in learning, and to teach him to use these tools. With them many of those who became leaders of the world educated themselves with no formal schooling. Then if more schooling was possible, using the same tools, exercises designed to develop the powers of the mind were introduced. Latin, Greek, rhetoric, mathematics, and logic were for this purpose. After such studies one was not looked upon as educated, but it was assumed that he had the equipment and skill

necessary to become an educated man. The study of medicine, law, the ministry, and later other occupations and professions could all be founded on reading, writing, and arithmetic used by a well disciplined mind.

All this is changed today. The 3 R's are badly neglected; Latin, Greek, rhetoric, and logic are gone; and mathematics so weakened as to be almost extinct. Their places have been taken by courses designed to prepare the pupil for "social living" without all this ado about disciplining the mind. We are told that a subject should be "useful." The test for its usefulness is not whether it aids in developing the mind but whether or not the subject matter will be used in later life. Even on this basis I cannot see why mathematics should be so neglected. "Socially significant" courses have been made up which are designed to teach the boy or girl how to get along with people. It is interesting that so much emphasis has been placed on such courses at the same time that the movies, radio, and ease of communication and travel have developed so extensively. These modern developments are continually emphasizing social adjustment. One might think that with such changes in society it may not be necessary to put so much emphasis in our schools on social living so that more attention could be given to developing the mind.

COURSES FOR DISCIPLINE OF THE MIND ARE NEGLECTED

THE IDEA THAT a subject should not be studied unless the information learned will be used in later life is silly. One afternoon last fall I watched the men on the practice field training for football. Now, as I understand the game, the idea is for one team to try to carry or kick or pass the ball in a certain direction against opposition from the other team. Had I judged what these men were doing on the training field on the same basis as that used by educators in evaluating subjects to be taught in our schools, I would have thought they were going through some rather ridiculous antics. They were vigorously pushing around the field a large object made of heavy timber which looked like a stanchion in a dairy barn. It didn't seem to me to be in any better location when they got through than when they began. Others had sacks that looked like duffel bags filled with something heavy. Some of these were hung up by ropes and some were just held by a player. Players were leaping and hugging these bags and tussling over them. Not a football was in sight. I haven't kept up on football lately, but I believe I would have noticed it if any of these contraptions had been used in a football game. It occurred to me as I watched the men on the practice field that the coach had the idea, which seems to be repulsive to so many of our educators, that

skill useful for the game they wished to play could be better developed by the "useless antics" than by doing nothing but always trying to push the football forward. I wonder if in the development of the powers of the mind such "useless subjects" may not also be of help.

Harry J. Fuller (1951), in a caustic criticism of the professors of education who foster the present changes in our high schools, addressing the University of Illinois Chapter of Phi Beta Kappa, said:

Persons of education know and have known for centuries that languages and literature, the arts and the sciences, constitute a rich, imaginative, concrete, and enduring source of valuable lessons in manners, ethics, behavior, personality development, beauty, and social adjustment. Under the guidance of able and wise teachers, students may extract from the study of the rise, decline, and fall of Rome, of Hamlet and Lear, of the lives of plants and animals, of Homer and da Vinci, of Mark Twain and Rousseau, facts and precepts that can mold their characters, broaden their minds, make of them sound and mature citizen-adults. Perhaps a line of Bernard Shaw's is pertinent to the antipathy of many education professors in these classical fields of human knowledge: "People who are not up on a thing are usually down on it."

I do not wish to imply that the humanities, arts and sciences should constitute the sole subject matter of high schools. I believe that certain social service courses have a valuable function in the education of young people, but I am convinced that the burgeoning of such courses has been excessive and beyond the limits of their value. I do not object to a small, well planned aggregation of these courses, but I am ready to buckle on my armour when the effects of such courses is to emasculate and vitiate the humanities and the pure sciences, on the assumption that the former are empty, moribund, and irrelevant relics of the past and that the latter are simply incidental to our contemporary invention of mechanical gadgets, jet planes, and atomic bombs.

It is true that many courses in literature, history, and mathematics are still offered in the high school, often with excellent teachers, but they have been seriously weakened in a number of ways. They are usually not required for graduation. Some high schools have no requirements for graduation except four years of attendance. Students are often required to choose between athletics or band and courses in mathematics or science. Perhaps the greatest factor in weakening all courses in high school is the growing attitude of school superintendents that a student must not be reported as failing.

Again Professor Fuller (1951), says:

The increasing failure of our public schools, under the stupefying meddling of our colleges of education, to provide young Americans with sound knowledge and training in the tools and intellectual methods of educated people, is tragic and ominous indeed, but it is perhaps less tragic and less ominous than their contribution to moral and ethical deterioration of the students entrusted to them. A strange and wondrous product of certain professional pedagogical minds is the teaching that the principle requirement for graduation from high school is length of classroom residence. According to these high priests of pedagogy, failing a high school student in his courses, or refusing to graduate him if he does not achieve a creditable proficiency in his studies, may engender in him profound and

permanent psychological aberrations, which will doubtless lead him into a life of crime, a career as a scribbler of obscenities on washroom walls, or to stick thumbtacks into his mother-in-law. Therefore, they cry, let us give a diploma to everyone who manages to sit in high-school classes for four years, whether or not he has learned anything. This practice recalls a conversation between Alice, during her brief but pleasant sojourn into Wonderland, and the Dodo, who remarked following the caucus race, "Everybody has won, and all must have prizes."

PREPARATION FOR LIFE AND PREPARATION FOR COLLEGE BOTH REQUIRE THINKING

THOSE WHO defend the newer policies will tell you that the old idea of making a high school merely a preparation for college is out-of-date. Since a majority of high school graduates do not go to college, it is unfair to subject them to the rigorous self-discipline from which the minority, only, would benefit. Such a view is ridiculous. I do not believe that college administrators should determine what is to be taught in high schools. I will agree that students in high schools should be taught to meet the problems of life and enjoy the finer things that society has to offer. I insist further, however, that a well disciplined mind, capable of concentrating for an extended period of time, a background in history and literature, an ability to express one's thoughts and experiences, and recognition of relative values are of the utmost importance in the preparation for life. There need be no difference in the education of the student who is going to college and the one who is not. If a difference is made, it should be in the direction of giving to the one who will not go to college more rigorous work in those subjects which demand sound thinking and power to express his thoughts. The boy who goes to college will have opportunities for more such training later.

HONEST EFFORT AIDS IN DEVELOPMENT OF CHARACTER

I CANNOT LEAVE this question of the lack of demand for hard work and sound training in our schools without referring to another problem that I believe is closely connected and is of great importance.

We are gravely concerned at present with the deterioration in the moral fiber brought to light by the increasing juvenile delinquency and divorce, and by dishonesty among government officials, businessmen, and students. I do not know that dishonesty is a result of our laxity in demanding honest work in our schools, but I do believe that moral stamina is strengthened by the early realization that one cannot get something for nothing, that the good things of life must be bought by honest effort.

A. J. Carlson, of the University of Chicago, in an address before the American Association for the Advancement of Science stated:

We see mental and moral weakness increasing everywhere about us, in our poorly and frivolously trained students, in our divorce courts, in our criminal courts, in our governing officials, at all levels in our civilization. As a physiologist I know of a specific chemical remedy which would check and ultimately eradicate such mental and moral flabbiness from us. That chemical is a simple one: iron, iron in the backbone.

It has been suggested that classes in character building be added to our schools. If such classes are to be more classes of the nature of the "socially significant" courses, I would oppose them. What we need is not classes in character, but teachers of character. We must not merely make appeals to the emotions, or preach, we must insist that the student think, and learn to like it. Character comes by doing things honestly, by learning not to shirk one's duty, and by not flinching from honest work. A class in character building would be like a class in English with no thought to express or a class in education with no subject to teach.

Whether or not one accepts the criticism of the high schools that I have made, everyone who has taught freshmen will, I am sure, agree that few of them have learned to think. Until the time when we can bring about a change in the policy in our high schools, one must take the freshmen as they are and start from there.

I like to teach freshmen. Perhaps it is because of a desire to help those who have not had a fair deal. Perhaps it is because it is so satisfying to see them develop. Perhaps it is because I always did like a good game. When one sees the boys and girls he has taught succeeding in their life's work, he feels that the game has been won.

THE OBJECTIVES IN A COLLEGE EDUCATION

WHAT SHALL BE our objectives in the education of these boys and girls? My discussion of their pre-college preparation has already revealed pretty well my convictions on that score. A committee of the faculty of Yale College (1829), 123 years ago, gave their opinion of the objectives of a college education with some, still applicable, suggestions on how to attain those objectives:

The groundwork of a thorough education must be broad, and deep, and solid. For a partial or superficial education, the support may be of looser materials and more hastily laid.

The two great points to be gained in intellectual culture, are the *discipline* and the *furniure of the mind*; expanding its powers, and storing it with knowledge. The former of these is, perhaps, the more important of the two. A commanding object, therefore, in a collegiate course, should be, to call into daily and vigorous exercise the faculties of the student. Those branches of study should be prescribed, and those modes of instruction adopted, which are best calculated to teach the art of fixing the attention, directing the train of thought, analyzing a subject proposed for investigation;

following, with accurate discrimination, the course of argument; balancing nicely the evidence presented to the judgment; awakening, elevating, and controlling the imagination; arranging, with skill, the treasures which memory gathers; rousing and guiding the powers of genius. All of this is not to be effected by a light or hasty course of study, by reading a few books, hearing a few lectures, and spending some months at a literary institution. The habits of thinking are to be formed by long continued and close application. If a dexterous performance of the manual operations, in many of the mechanical arts, requires an apprenticeship, with diligent attention for years; much more does the training of the powers of the mind demand vigorous, and steady and systematic effort.

This is a statement of aims for a liberal arts college. For a college that prepares for a trade or profession it would be necessary to add as an objective the training in the information and skills necessary for the trade or profession. Let me emphasize that the training for the purpose of making a living should be added to the objectives suggested by the Yale faculty, and not substituted for them. In some professions, notably engineering, the technical training required is so extensive that colleges have lessened the requirements for the cultural background. But educators in engineering are well aware that their graduates are seriously handicapped by this.

We may set our objectives in a college education, then, as (1) the development of a disciplined mind capable of sustained attention and practiced in sound thinking; (2) a mind well versed in those things which form the background of our culture; (3) a person capable of expressing his ideas and discussing affairs intelligently with others; (4) a person trained in the essentials of his trade or profession.

THE SCIENCES ARE AIDS IN ATTAINING OUR OBJECTIVES

IT IS HARDLY necessary to call attention to the importance of science as a means toward our objectives of teaching students good habits of thinking. The whole development of science is a process in the development of the mind. It is a study in observation, experimentation, organization of information, statements of generalizations or laws, development of theories, testing of theories, prediction of undiscovered facts or unobserved occurrences and new applications.

THE SCIENCES ARE AIDS IN TEACHING LANGUAGE

SCIENCES ARE an excellent tool for the teaching of clear expression of ideas. It is my conviction that if such courses as the sciences, history, and economics were properly taught there would be far less use for formal courses in English. Science cannot be taught without teaching oral and written language. We shall never be successful in teaching our students

to use effective language if we leave the teaching of it wholly to the Department of English and neglect it in other courses. English cannot be taught separately from subject matter. The most important requirement for good use of language is to have something to say. Courses planned to teach one to use English without subject matter to talk or write about are like a windmill in a vacuum. The sciences offer excellent subject matter to use in teaching one how to say something. The laws of science need to be stated with precision. In arguments or explanations sentences must be clear and in the right order. Correct words must be chosen. Punctuation must be used properly.

One of the best courses in English offered in the high school is geometry. I do not favor geometry chiefly because it teaches the boy that the sum of the angles of a triangle equals 180 degrees or that the area of a circle is found by the value of pi times the radius squared (though such facts do have much practical value). Geometry is of value because it teaches clear, logical thinking and the use of accurate statements in correct order. There is no other course offered in high schools that can take its place. I taught geometry for a number of years. The students in my class were not only boys and girls of the usual high school age, but many were older fellows from the remote farms and cattle and sheep ranches of southern Utah. You can well imagine their ability in language. You can also imagine the effort it required for them to state step by step their proof that they could measure by triangulation the distance across the canyon in which the school was located. But they had something to say and they learned how to say it. Even their grammar and spelling were improved by their desire to say it right. It must be admitted that as they made side bets with each other as to the outcome of the measurement across the canyon with a surveyor's tape their language was not in the best King's English. These classes in geometry were some of the most interesting and I believe the most useful I have ever taught. It is distressing to me to observe the gradual removal of geometry from the curriculum of high schools with nothing equivalent to take its place.

Unfortunately teaching in science lends itself to a recent fad practiced now in all departments, which I consider to be an important factor in weakening the learning of written languages. Because in science, questions can be asked which require a definite answer, perhaps only a word or a number, one is tempted to use extensively the so-called objective examination questions which can be answered by encircling a letter, blackening a space with a pencil, writing T or F, or underscoring a word. These tests require no writing, no organization of thoughts, no self-expression on the part of the student. The teaching value of these tests is largely confined to the instructor who must make considerable effort in organizing and expressing questions properly so that the student can answer with his mark. I never use such tests without thinking of talking to an Indian.

To get any information I would have to state my questions in such a way that he could answer with a grunt, a shake of the head, or a shrug of the shoulders. But then, I was not concerned with teaching the Indian how to express his thoughts. As a final means of evaluation, such tests may be of some use, but as a teaching aid, I see little value in them. They certainly fail to aid in teaching expression while a properly prepared test can be of great value.

THE STUDY OF SCIENCE HAS CULTURAL VALUES

SCIENCE HAS its place in education for our stated objectives because of its cultural value. I am aware that a great deal has been written lately blaming the ascendancy of science for many of the social ills of today and accusing the scientist of being a cold materialist. It is suggested that only greater emphasis on the humanities can save our souls. If those who make such statements are pressed for a more complete explanation of their views, it becomes apparent that the real villain is the technician or engineer who applies the sciences to make bigger and more ingenious machines capable of producing more things both for construction and destruction (especially for destruction). Of course, the scientist is also to blame, for it is he who makes the basic discoveries for the engineer. Now I will agree that engineers and scientists would be more valuable to society and would lead fuller and richer lives if they knew more about the works of great authors and artists and more about history and sociology and economics. Just as certainly, the historian, the sociologist, the artist, and the poet would be more valuable to society and would lead fuller and richer lives if they knew more about the sciences.

Thermodynamics and history both show that one cannot get something for nothing. The beauty of a sunset is no less impressive because the observer has learned something about refraction of light. A Pasteur searching in his laboratory for means to free mankind from bondage to disease can be as noble as a Moses freeing his people from bondage to the Egyptians. One's feeling of humility is inspired no less by the study of the visible universe than by David's pleadings. The feeling of being one with the Infinite will probably be made more profound through a study of geology, evolution, and matter and energy than a reading of Bunyon's "Pilgrim's Progress."

In the experimental sciences a student learns to look for evidence before accepting all that he reads or hears. He learns to test ideas with controlled experiments. He learns to respect the opinions of those better trained than he, but he reserves the right to question conclusions that do not agree with the results of his own experiments. He learns that certain results follow certain causes. If he would attain a desired end, he

must do required things. One does not get something for nothing. He can think and act for himself. These are wholesome attitudes which are carried over into his everyday life.

I do not like the way we use the term "the humanities." We infer that those subjects included under this term contain the elements by which humans are distinguished from other creations. In the humanities we deal with the emotions, love and hate, fear, anger, jealousy, love of the beautiful, the desire to associate with others, as well as feelings aroused by art and music. We, however, exclude that which, probably more than any other quality, distinguishes man from what we like to call the beasts. We have all seen animals show all the emotions of hate, fear, anger, jealousy. The bellowing of a cow in a rage can sway the emotions of a herd in a manner which is the envy of many an orator. We know how animals like to associate with their kind and exclude from their society individuals that are different. We have seen them show appreciation of the beautiful in color and in music. If man is to be greater than the animals, he must not belittle the qualities in which he resembles them, but must add that thing which sets him apart from them: the disciplined mind.

HUMAN PROGRESS IS DEPENDENT ON SCIENCE

IF ONE WOULD understand the history of the progress of man he must have a partial understanding of advances in science. The Renaissance began in the humanities, but the work of men like Copernicus, Galileo, Bacon, Boyle, and Newton had much to do with the downfall of dogma. The idea that assumptions could be tested by controlled experiments, the idea that man need not accept all the ills that beset him, but could alter his environment for his own betterment, these are some of the greatest factors in his progress.

Even today, with the complaint that there is too much altering of environment and too many machines to do the work we wish done, we must admit that the improvement of the lot of the common man is the result of technical progress. Amelia Bloomer, Lucy Stone, and Susan B. Anthony are honored as the emancipators of women. However, Eli Whitney, James Hargreaves, and Richard Arkwright are far more responsible for the change. They took the chores of spinning and weaving out of the homes and gave women time for leisure. The invention of the automobile and of machinery to build roads has done more to do away with sectionalism than has all the work of reformers and internationalists. The starving millions of China would no doubt be more ready to listen to the Sermon on the Mount and respect the dignity of the individual if their material needs were more nearly met. None of our great social advances would have been possible if our dynamic economic development had

not supplied the means. The one who would discuss and interpret great social changes should know something about how they are brought about. An understanding of how scientists work, or as Dr. Conant (1951), calls it, "the methods and strategy of science," should be had by those who hope to direct human affairs.

SCIENCE IS ALIVE AND CHANGING

SCIENCE is interesting to teach because it is so alive and changing. One sees not just new inventions, or new dyes and drugs and explosives, or new and cheaper ways for getting aluminum or magnesium from their ores, but also new fundamental concepts of the nature of matter and of the universe.

In the early years of my study of science I became aware of a feeling which one might call smugness on the part of many writers and speakers in science. Although discoveries had already been made which were to blast such a view, there persisted among many the idea that science had already made all the really fundamental discoveries. This idea had appeared in the writing of one of our Nobel Prize winners in physics, who maintained that the universe was made up of atoms in various states of union with each other and in motion in a space filled with luminous ether through which waves of radiant energy passed at a known velocity. The laws of behavior of atoms and light were known. Further work by investigators would largely consist of measurements to another decimal point of accuracy. This did not mean that new inventions would not be made. Improvements in automobiles, production of jet engines, and new designs of airplanes, the development of new drugs, or fluorescent dyes for junior's socks result merely from new applications of principles long known. Better microscopes could be made, but they could not see any smaller objects, for the minuteness of the object to be seen by the microscope is limited by the wave length of visible light. Greater telescopes might be produced, but would surely only reveal more of what had already been seen.

With this view there was also the opinion expressed by many that the universe including man was wholly mechanistic. If one knew the positions and the motions of all atoms, one could predict all future events. The development of life and the evolution of man were the result of a fortuitous concourse of atoms (Brownell 1926), a view more deterministic than that of the most conservative Calvinist.

New discoveries, then already made, have changed all this. Atoms are not the eternal unchanging building blocks of all material things. They may come and go. Matter and energy are one. Uncertainty principles are now talked about. The universe is expanding. Light is particles

with wave characteristics. Particles of matter have frequencies like radiant energy. Crystals have some of the properties of living matter. During the past few years the fundamental conceptions concerning the universe have changed more than in a thousand years before. It has been exciting to live during this time. The interest aroused by new discoveries and new conceptions is not confined to the great scientists, but reaches down to the mere beginner. It makes teaching more satisfying to lead one's students to such a wonderful new world.

METHODS OF TEACHING SCIENCE

I HAVE SUGGESTED that the physical sciences could well be included in those branches of study which would be acceptable to the Yale College faculty (1829), when they said:

Those branches of study should be prescribed and those modes of instruction adopted, which are best calculated to teach the art of fixing the attention, directing the train of thought, analyzing a subject proposed for investigation, following with accurate discrimination the course of an argument . . .

How often, however, do we find courses in chemistry, physics, or biology, both in high school and college which fail to do any of these things? How many of you have worked in the chemistry laboratory filling dozens of test tubes with pairs of solutions which did or did not produce a precipitate, or a color, or a bad odor, and then recorded the results in certain blanks in the manual without feeling that you were doing much to develop the mind?

Not only must we choose the branch of study, but more important, we must adopt the best "modes of instruction." To my mind the greatest waste of time, the most useless expenditure of energy in teaching, is in many of the purely descriptive courses (or as the teachers of the courses like to call them, "the practical" or "applied" courses). Text-books in great numbers are published filled with facts for students in high school and college general science, college chemistry, physics, and biology. A book on science will tell one how far it is from the earth to the sun, and what the earth weighs. In one paragraph it will describe the action of a locomotive, or an electric motor, or a petroleum distilling tower. It will tell one how soap is made, how to put a splint on a broken leg, and how to brush the teeth with vertical rather than horizontal strokes. If you think such courses are practical or "applied," try testing the students on the facts a month later. How does a teacher of such a course justify his own presence? Why should anyone pay him a salary to repeat these facts from the text book or even to add other bits which the author forgot to mention? This is not the function of a teacher.

Now the understanding of any science will demand that one be familiar with many facts, the more the better, but the knowledge becomes

useful only as the facts are organized and tied together with underlying principles. Then one set of facts may be predicted from another.

It is the teacher's job to aid in this organization of facts and the development of principles:

Carbon dioxide is slightly soluble in water.

The solubility is proportional to the pressure.

The resulting solution is slightly acidic.

Sodium carbonate solution is basic in reaction.

Calcium carbonate is only slightly soluble.

As isolated facts these have limited usefulness and would soon be forgotten. If, however, a few principles concerning reversible reactions are understood, one sees that these facts are closely related to:

Baking powders and fire extinguishers.

Hardness in water.

The pH of blood.

The formation of caves and stalactites.

The alkalinity of soil solutions.

Soda water and commercial oyster farming.

So too in more advanced courses—organic chemistry or physics whether for majors in chemistry, premedics, forestry, soils, or home economics—the effort of the teacher should be directed to teaching the fundamental principles and the means of classifying the facts and applications. Only then will the student understand the applications and remember the facts. If the student fails to get the background he gains little from the course.

LEARN A SCIENCE BY ACTING LIKE A SCIENTIST

IN THE STUDY of a subject in science, the student, especially the beginning student, should be brought as nearly as possible to the position of going through the same experiences as did the men who made the discoveries and developed the subject. The student will best understand science as he comes nearest to being a scientist. He must bring himself as nearly as possible to thinking and analyzing the same way as the scientist does when he is developing a new principle. James B. Conant (1951), president of Harvard University, advocates what he calls the method of "case histories" for those who are interested in science for its cultural and social value. I believe his method is also the best for the beginning scientist. Professor Conant would not waste the time of the student in an enumeration of the many wonderful accomplishments of science, but rather would take a few fundamental discoveries and developments and follow through their case histories.

He chooses, for example, the study of Boyle's law and follows through the gradual evolution of the ideas concerning the nature of gases, gaseous

pressure, barometric pressure, and vacuum pumps. The student learns not only about Boyle's law, relating the volume and pressure of a sample gas, but far more important, he learns something about how a scientist thinks and works. The atomic theory and the nature of combustion are each developed by Professor Conant in the same way.

Teach a boy to become a scientist by leading him to behave as a scientist. If he is studying only to understand the importance of science in human affairs, he will understand scientists and their work better if he too has tried to act as a scientist.

THERE ARE NO AXIOMS IN THE PHYSICAL SCIENCES

THERE ARE NO axioms in the physical sciences. All that is known is based on observations and experimentation. Many of our recent textbooks, however, impress the student with the idea that most of the conceptions and theories are axiomatic. Most textbooks of chemistry for freshmen have in the first chapter a statement outlining "the scientific method." There is, first, the collection of data from observation; second, the observations are organized, and observable generalizations are stated as laws; third, theories are advanced to explain the law, i.e., to place the laws in the same category with other laws; fourth, by deduction the results of untried experiments are predicted; fifth, prediction is tested by experimentation. Unfortunately this statement of the scientific method is given as though it were itself an axiom of science. Too often one will find in the remaining pages of the book no application of this method.

In a textbook written for freshmen by one of our most prominent chemists (Pauling 1950) one finds, except for a short paragraph in small type, no explanation for assuming the existence of atoms. The fascinating stories of the experiments and bold hypotheses leading to our present conception of the structure of atoms are not given. The chapter dealing with the periodic classification of the elements begins:

One of the most valuable parts of chemistry theory is the periodic law. In its modern form this law states simply that the properties of the chemical elements are not arbitrary, but depend upon the structure of the atom and vary with the atomic number in a systematic way. The important point is that this dependence involves a crude periodicity which shows itself in the periodic recurrence of characteristic properties.

Stated as it is, without any explanation to show how the theory came to be known, this looks much like an axiom or an arbitrary statement by some supreme authority. In the following pages of the book properties of atoms are deduced from the generalizations of the periodic classification.

In physics, too, the same trend is observed. Some teachers and textbooks approach the subject of mechanics by writing a few mathematical

equations and deducing all the facts of mechanics from the equations. Teachers who attempt to teach beginners by this method have forgotten their own first years in college.

Levers had no doubt been used by men for ages before someone made measurements of forces and loads and lengths of arms and found that, using the proper units, the force times the length of its arm is equal to the load times the length of its arm. I imagine that the fellow got quite a thrill from his discovery. Let us not rob the freshman of all such thrills. Let him discover things too!

If the present trend continues, I shall expect soon (after a few details have been attended to) a freshman text in the physical sciences, beginning, of course, with a statement of "the scientific method." (That is always given.) Then there will be Einstein's equation $E=mc^2$, followed by a few equations of wave mechanics and the quantum theory. From these the whole of physics and chemistry will be deduced. Such a book would be a marvelous thing, but it is the last book I would choose for beginners in physical science. Such an approach to the physical sciences is confusing and misleading to the beginner. It is difficult, at best, to impress the student that the only authority in science is controlled experimentation and observation, and that conceptions and theories of science were not found written on tablets of stone. We are told that even the brilliant Sir Isaac Newton wrote the equations for force and motion after being hit by the falling apple, not before. I repeat—teach science by helping the students to think and to act as scientists.

THE TEACHER OF SCIENCE HAS A RESPONSIBLE POSITION

NOW IF THERE are any younger persons here tonight who are looking forward to being teachers of science, let me warn you that there will be some difficult tasks and some disappointments. First of all, you will be shocked by the profound ignorance of the freshmen, of which I have already spoken. Then you will also be surprised to find that a number of students are not at all interested in overcoming that ignorance unless it can be done with no effort on their part. This will not be a large number, but every college gets its share of such persons. The students, too, will be shocked to find that serious effort on their part is also necessary. They will become frightened and easily discouraged when presented with a problem to solve. Great patience will be necessary, and there will be the disappointment of realizing that you are failing to awaken some of the boys and girls. That is the most discouraging part of teaching. You will wish that classes were smaller or that less time were necessary for preparation of demonstrations so that you could give more time to individual students.

You will become aware that as a teacher of science you are in a responsible position. So many professions and fields of study depend on science that your success or failure with a student may determine whether or not he will be able to go on with his chosen career. The teachers of freshman chemistry classes in our colleges probably have more to do with the selection of the future physicians than do members of the admissions committee of medical schools. The heartaches and the wasted expense of failures in medical schools would be lessened if these freshmen teachers were more awake to their responsibilities. It is no kindness to a student to pass him on unprepared to compete in advanced work or in his profession.

College administrators are paying more attention to the students that are slow to adapt themselves to college work or are incapable of doing the work required in the more difficult courses. Orientation courses are offered. Better advisory systems are built up. This is an excellent move. No doubt more can be done to prevent the failure of so many of the weaker students.

WE MUST FIND AND PREPARE THE FUTURE LEADERS

I AM AFRAID, however, that while we are so concerned with the weaker students, we are neglecting a number of others who, in proportion to the effort expended on them, would make a far greater contribution to society. Oh, we know that the superior student will be able to pass the course without much attention. Being able to pass the course is not sufficient. The requirements of the course are set up to permit the average or weaker student to pass. If we permit the superior student to get by with little better work than is done by the mediocre, we are doing a disservice to the student and the state. The progress of the human race is made possible by what some writers estimate to be as small as four or five percent of the people. We need leaders. Our government has too often and too long been headed by mediocre men. In our schools we must not only encourage the few superior students to do superior work, we must demand it. Superior work is not just more of the same kind done by the average fellow, not just more classes, but far better work. You will meet some of these outstanding boys and girls in your classes. Encourage them. There seems to be almost no limit to the power of the human mind, but the maximum that will be accomplished will depend on the development of the mind by exercise. Even the best of the students will be inclined to stop short of their maximum ability. Do not let them get by with the little effort it requires for them to do as well as the average student. Make leaders of them.

In conclusion, if you are fascinated by science, if you like research, if you like people, if it interests you to see a young fellow develop from the shy freshman to the capable self-confident leader, if you don't insist on too much pay for your work, if you want a job where the satisfaction of your work is yearly increased as you watch your product increase in value, be a teacher! You'll like it, I do! !

REFERENCES CITED

- Brownell, Baker. The new universe. New York, Van Nostrand, 1926. p. 57-58.
Conant, James B. Science and common sense. New Haven, Conn., Yale Univ-Press, 1951.
Daiches, David. A Briton looks at education in the United States. New York Herald Tribune, August 15, 1951.
Fuller, Harry J. The emperor's new clothes, or Pirus demented. Sci. Monthly 72:32-41. 1951.
Pauling, Linus. College chemistry. San Francisco, Freeman, 1950.
Yale College. Committee of the Faculty. The nature of a liberal education. Amer. Jour. Sci. 15:297-351. 1829.

